Virtual Reality Simulation in Laparoscopic Surgical Education

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LIST OF PAPERS

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Virtual reality simulator training equals mechanical robotic training in improving robot-assisted basic suturing skills, Surg. End., 2006, 20(10), 1565-1569

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1 INTRODUCTION

1.1 Background

"See one, do one, teach one" is a tenet in surgical education attributed to one of the pioneers in modern surgical education, William S. Halsted[1-6]. Halsted was inspired by his trips to Germany which at the time was superior to the United States with regards to academia and structured surgical training. In his article from 1904, "The training of the surgeon"[7], the apprenticeships model was introduced, which later resulted in the surgical residency system in the United States[1,4,8-14]. This model is based on surgical novices being taught surgical skills and strategies in the operating room by more experienced surgeons.

In the late 1980`s laparoscopic surgery was introduced. It quickly gained wide acceptance because of less surgical trauma resulting in less pain, shorter hospital stay, faster return to normal activity, reduced cost and improved cosmetic results[15-17]. Laparoscopic surgery required new skills and strategies compared to open surgery; the operation field had to be viewed indirectly with degraded image quality on a two dimensional screen via a camera held by an assistant[11,18,19]. Tissue and organs had to be manipulated indirectly via long instruments through small ports resulting in reduced degrees of freedom and reduced tactile feedback[8,20-22]. This was further complicated by the "fulcrum effect"[23], resulting in the tip of the instrument moving in the opposite direction of the surgeon's hand.

Skills learned in open surgery are not transferable to laparoscopic surgery[24-26] and surgeons, who had only been trained in open surgery, viewed laparoscopic surgery as more complicated[27-30]. During the initial phase of implementation, operation time and complication rates were higher for laparoscopic surgery compared to traditional open surgery[31-35] and the implementation of laparoscopic surgery has been described by Cuschieri as "…the biggest unaudited free-for-all in the history of surgery." because of the unstructured expansion[36,37].

The increased complication rates combined with the notion that laparoscopic surgery was more complicated than open surgery and not suitable to be taught and learned in the traditional "Halstedian way", led to basic laparoscopic training being moved out of the operating room[38,39]. This change was later fueled by the reduced work hours for residents, the introduction of robotic surgery, increased focus on reducing the cost of surgical training and most importantly, increased focus on patient safety[38,40-47].

Reznick introduced the concept of using virtual reality in surgical training in 1993[40]. The same year Satava published the first article describing a virtual reality surgical simulator[40,48], inspired by the use of simulators in pilot training[49,50].

The need to teach and learn surgical skills and strategies outside the operating room had been addressed prior to the introduction of surgical simulators[51-53]. It was however not until the introduction of new training modalities in the form of virtual reality simulators that the number of studies focusing on teaching and testing surgical skills and strategies increased.

The ultimate goal of using simulators in surgical education is to improve patient outcome by being able to train and test the surgical performance of residents in a safe, standardized environment to insure surgical competence before performing live surgery on patients[1,48,49,54-59].

1.2 Surgical competence

Surgical competence can be defined as being in possession of sufficient cognitive, affective and technical skills, thus being able to perform a surgical task at a level that is acceptable [60-65]. Cognitive and affective skills are based on personality traits and mental qualities, such as theoretical knowledge, communication skills, empathy, motivation, leadership skills, stress-coping strategies, self-belief, decision-making skills and adaptability, i.e. non-motor skills[53,65-70]. Surgical competence may therefore be defined as the combination of theoretical knowledge and mental skills (surgical strategy) and motor skills (surgical technique).

It has been stated that surgical competence is more dependent on surgical strategy (75%) than surgical technique (25%)[51,71], but lacking technical skills per se results in the surgeon being incompetent [72,73]. Until the introduction of simulators, most of the surgical literature focused on surgical strategy rather than surgical technique[40]. Improving the level of surgical strategy requires only theoretical teaching and learning. Improving surgical technique requires motor skill teaching and learning.

This thesis focuses on how to teach and learn surgical technique in laparoscopic surgery using virtual reality simulators.

1.3 Surgical technique

"Technique" in general can be defined as a skillful way of doing something[74]. Good surgical technique can be defined as precise and efficient movements to execute a specified surgical task without errors[67,75]. Different surgical techniques are made up of different surgical skills, i.e. motor skills. The level of surgical skills are not associated with the level of theoretical knowledge or academic achievements in the same way as there is no association between clinical performance and academic achievement for doctors in non-surgical specialities[71,76,77]. Motor skills therefore need to be learned by practical training.

1.4 Principles of motor skill learning

The principles of acquiring surgical skills are similar to those applied when learning motor skills in sports and music[40,51,78]. These principles should therefore be applied in the education of surgeons[40,62]. Some of the principles most often referred to in the surgical literature have been the basis of the studies in this thesis. They are summarized in Table 1 and will be explained in the following sections.

Fundamental principles of motor skill learning
Learning can be visualized by performance curves which are made up of four phases (baseline, increase, roof and decline)
Learning takes place in three stages (cognitive, associative, autonomous)
Basic skills should be learn before complex skills
Part task training is more effective than whole task training
Distributed training is more effective than massed training
Motivation is important for effective learning
Feedback is important for effective learning

Table 1: Fundamental principles of motor skill learning

1.4.1 The learning curve

The process of learning motor skills can be visualized by a learning curve where skills are measured at different times during the learning period. Learning is an internal process that only can be assessed indirectly by measuring performance[78,79]. A more correct expression may therefore be "performance curve"[80].

A standardized performance curve (Figure 1) for surgical skills consists of four phases: 1) the baseline performance[81], 2) the increase in skills[78] with the highest increase in skills during the early part of training, followed by a more gradual improvement[82-85] until phase 3 where skills do not improve despite continuing practice and training [79], and finally phase 4 where skill level decreases because of lack of retention of skills[86,87] or age-induced decline in skills[88-90]. If skills are tested multiple times during a shorter period of time, increase in performance may take place in plateaus rather than a continual increase in skills[80,82,91] (Figure 2).

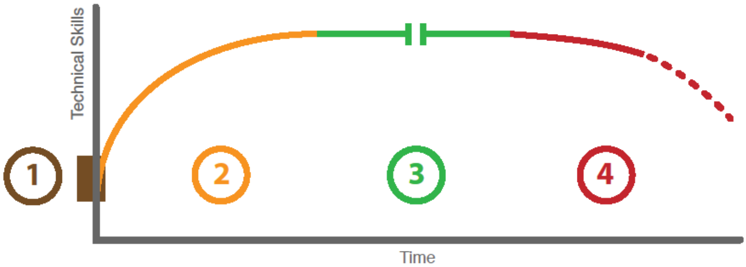

Figure 1: A standardized performance curve consisting of four phases
Phase 1; baseline performance, Phase 2; increase in performance as results of training, Phase 3; performance "roof" (no increase in performance despite continuous practice and training), Phase 4; decline in skills.

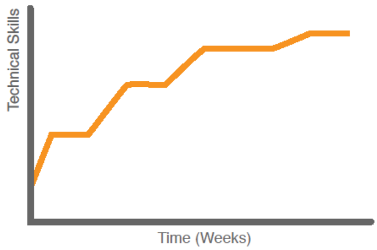

Figure 2: In phase 2, learning may take place in intervals followed by plateaus where skills are stable despite continuing training.

1.4.2 Three stages of motor skill learning

In the surgical literature, researchers most often refer to surgical skills learning taking place in three stages; a cognitive stage, an associative stage and an autonomous stage[12,83,92]. In the cognitive stage the trainee gains understanding of the task to be learned and mastered; the purpose of the skill and its different steps. In the associative stage the skill is practiced until it

is mastered, and in the autonomous stage the skill is practiced until it can be done automatically with minimal or no cognitive input.
There is no strict transition between the stages and the trainee will alter between the two first stages until the skill is mastered repeatedly in an automated fashion in the third stage.
During the two first stages the trainee needs to focus most of his/her attention on how to perform the specific skill correctly. This implies that the trainee may use all his/her attentional capacity to perform the skill[72,93]. If the skill is to be performed during live surgery in the operating room, the attentional resources needed may exceed the attentional capacity of the trainee, and learning may not take place. If the skill is taught and trained in a simulated environment, all attention can be focused on the skill, thereby improve learning and reduce the time needed to perform the skill competently and in an automated fashion. The potential effect of this “pre-training” is the main advantage of simulator training.

1.4.3 Principles of surgical skills training

Surgical skills training should adhere to well-known principles of motor skill learning:

Complex skills are made up of basic skills, and basic skills should therefore be learned before complex skills[94]. Improving basic skills may improve performance of a more complex skill[95]. Part-task training has been shown to be more effective than whole-task training when learning complex skills[3,96,97]. In part-task training the complex skill to be mastered is deconstructed into different parts which are trained individually before they are combined sequentially into the complex skill.

The effect of learning is increased if training is distributed over multiple shorter training sessions instead of one long training session[79,98,99]. This is more important with increasing complexity of the task to be learned[100]. The ideal intervals between these training sessions are not known, but studies suggest that too long intervals are associated with reduced training effect[101].

Motivation is a key component for training to be effective[102,103] and for the trainees’ motivation to participate in a training program[104-107].

All learning is dependent on the trainee receiving continuous feedback during training[107,108]. This feedback helps the trainee to maintain motivation and to be aware of which subset of skills that are mastered and which are not. This helps the trainee being able to master the complete skill faster and to learn the best technique the first time. It takes longer to “unlearn” a suboptimal technique before mastering the optimal technique than to learn the optimal technique correctly the first time[92]. Feedback during training may be given to the trainee by the teacher/mentor or a virtual reality simulator.

These principles define the basis on which training and acquisition of surgical skills occur during actual surgery, or when using surgical simulators.

1.5 Simulators

Simulator may be defined as “a device or exercise that enables the participant to reproduce or represent, under test conditions, phenomena that are likely to occur in actual performance”[4]. Depending on how many aspects of real life is reproduced, simulators can be categorized as either low-fidelity or high-fidelity[109]. High-fidelity simulator simulates more aspects of surgical skills or procedures compared to low-fidelity simulators.

There are three types of simulators: 1) computer based simulators, most often referred to as virtual reality simulators, 2) physical simulators and 3) hybrid simulators.

1.5.1 Virtual reality simulators

Virtual reality may be defined as “a collection of technologies which allow people to interact efficiently with three-dimensional computerized databases in real time using their natural senses and skills”[110].

When using a virtual reality simulator the trainee uses a human-computer interface to interact with the simulated surgical environment using virtual reality surgical. This is similar to a computer game player interacting with a game environment using a controller.

Virtual reality simulators are able to record surgical performance parameters and give feedback to the trainee based on these parameters. This gives the trainee the possibility to track personal changes in performance and to compare his or her performance to other trainees. These simulators do not require consumables such as surgical instruments, animate or inanimate tissue, sutures etc. This eases preparation of the simulator between different training sessions and reduces the need for storage space.

Virtual reality simulators are however more expensive to buy than physical simulators and software needs to be upgraded regularly. Most virtual reality simulators lack tactile feedback and the physical properties of the simulated tissue has reduced realism.

1.5.2 Physical simulators

A physical simulator consists of a box, camera and screen to visualize the inside of the box. When using physical simulators the trainee interacts with the simulated physical environment, consisting of animate or inanimate tissue, using ordinary laparoscopic instruments. The benefit of using a physical simulator is that the trainee uses real instruments and interacts with a physical environment that may consists of animal organs or tissue with optimal tactile feedback.

Physical simulators lack the ability to track performance and give feedback, but physical properties, including tactile feedback and the possibility to use animate tissue, is superior compared to virtual reality simulators. Physical simulators are also less expensive to purchase[111]. Although one study reports that trainees prefer physical simulators over virtual reality simulators[112], no clear advantage in training effect has been shown when comparing box trainers and virtual reality simulators in manual laparoscopic training[5,113-120], and combining both types of simulators have been found to result in better training effect than either one alone[121].

1.5.3 Hybrid simulators

Hybrid simulators are a combination of physical simulators and computer based simulators. The exercises are performed in a physical simulator with standard laparoscopic equipment. During training the simulator is able to track the movement of instruments and give feedback based on recorded data the same way as a virtual reality simulator.

1.5.4 Live animal training

The training most similar to surgery on real patients is obtained using anesthetized live animal in surgical skills training[122,123]. The disadvantage compared to a virtual reality simulator is that external feedback only can be given if an instructor is present, it requires more logistics, more economical resources, it has ethical concerns and training using animals is not allowed in some countries[50,52,116]. Virtual reality simulators thus hold the potential to reduce the number of animals used in laparoscopic surgical skills training[49,124]. This aspect is rarely focused on in the literature, and studies comparing virtual reality simulator training and live animal training had not been published during the work with this thesis.

This thesis will focus on using virtual reality simulation in surgical education with focus on gastric surgery. It will not cover simulator design and development[125-127].

1.6 Validation of virtual reality simulators

Validity can be defined as "being correct and in conformity with reality"[38]. Validity has traditionally been divided into subcategories in the literature focusing on simulators in surgical education. This subdivision is not used in this thesis as it does not add clarity to the understanding of validity and because it has been omitted in fields other than surgical education[128]. Virtual reality simulators can be used to train and test surgical skills.

1.6.1 Virtual reality simulators used to train surgical skills

When simulators are used to train surgical skills, i.e. to increase the level of surgical skills, the skills of an individual needs to be measured twice at two different points in time: before and after training. If skill is measured only once, it is not possible to conclude whether the skill level has increased, since initial skill level is not known.

Multiple studies have been performed, most of which conclude that virtual reality simulator training results in increased level of surgical skills in laparoscopic surgery[115,117,118,120,129-146]. Some of these studies tested surgical skills in the operating room[135,137,140,145]. Some studies report no effect of virtual reality simulator training[116,147-150].

To evaluate surgical skills improvement some studies applied different tests before and after training or tested skills only after training[116,130,135-140,144,147,151] , i.e. they tested skills only at one point on the performance curve. Some studies do not specify whether feedback was given or if other types of surgical activity was performed by trainees during the training period[5,117,130,132,137,152]. Factors, such as feedback from an instructor and operating room training, may increase training effect. These factors are rarely discussed as limitations. Some studies also report that feedback from an instructor is unnecessary to increase surgical skills[6,153].

1.6.2 Virtual reality simulators used to test surgical skills

When simulators are used to test surgical skills it is only necessary to test each subjects at one point in time, i.e. at one point on the learning curve.

Virtual reality simulators have been used to differentiate between surgeons with presumed higher surgical performance i.e. between expert surgeons and novices. Simulators have been found to differentiate between experienced surgeons and less experienced surgeons in 3 of 3 parameters in one study[154]. Other studies find that simulators differentiate between surgeons with different level of experience for some, but not all parameters[25,155-172] and virtual reality simulator performance have been found to correlate to operating room performance for some but not all parameters[168,173]. Experts tend, however, to be more consistent in their performance when a task is performed repeatedly[154,163].

1.7 Laparoscopic surgery and computer game playing

The level of surgical performance in general seems to be related to visuospatial ability[174-179]. Visuospatial ability may be defined as the ability to search the visual field apprehending the forms, shapes and positions of objects, form mental representations of these forms, shapes and positions and manipulating such representations mentally[180]. The relationship between surgical performance and visuospatial ability may be explained by surgical performance being dependent on mental skills as well as pure motor skills.

Several studies in other fields than surgery have demonstrated that computer game playing also is associated with higher motor and visuospatial skills[181-188]. Virtual reality simulators share features with computer games where virtual objects are manipulated in a virtual environment using a human computer interface or controller. Laparoscopic surgery also has common aspects with computer games where objects in a 3-dimentional environment are manipulated while visualized indirectly on a 2-dimentional screen. This led to the publication of studies investigating the effect of computer game playing on laparoscopic skills[81,86,146,153,189-209]. The results of these studies were divergent.

1.8 Motivation for the thesis

When the work with this thesis started, studies focusing on simulators in surgical education had started to increase. The initial plan was to focus on the role of virtual reality simulators in

robot assisted laparoscopic surgery. The first study therefore focused on comparing the effect of training robot assisted suturing using a physical simulator compared to similar training using a virtual reality robot simulator. This was the first published study investigating the effect of virtual reality simulator training in robot assisted laparoscopic surgery.
Robot assisted laparoscopic, and thoracoscopic, surgery did however not add to the surgical armamentarium as expected, and robot assisted surgery did not gain wide acceptance at that time, except for their useprostatectomy[210,211]. The focus was therefore changed to manual laparoscopy after Study 1.

After the introduction of virtual reality simulators and studies concluding that virtual reality simulator training increased laparoscopic skills, some Norwegian hospitals started to purchase simulators. These simulators were rarely included in a training curriculum.
Most published studies investigating the training effect of virtual reality simulators included other factors such as operating room practice and feedback from an instructor. These factors may result in training effect in addition to the potential effect of simulator training. The aim of Study 2was to investigated the effect of virtual reality simulator training per se on manual laparoscopic suturing skills.

Based on the divergent results of studies focusing on the effect of computer game playing on laparoscopic skills, the aim of Study 3 was to investigate the effect of previous computer game playing on baseline laparoscopic skills (phase 1 of the performance curve) by testing performance using a virtual reality simulator.

Virtual reality simulators holds the potential to reduce the use of live animals in surgical training[49]. No study had been published comparing virtual reality training to live animal training. The aim of Study 4 was to investigate this aspect.
Study 4 also sought to investigate if it was possible to define a subgroup of surgeons who evaluated virtual reality simulator training equal to live animal training. The use of simulator labs in a clinical setting is not widespread, and the use of these labs are variable at hospitals that have such training facilities[212]. Defining a subgroup of surgeons who rate simulator training high compared to animal training would be important when designing local curriculums and training facilities.

In summary: Based on principles of motor skill learning and similar published studies, the aim of this thesis was to focus on the use of virtual reality laparoscopic simulators in training of a fundamental laparoscopic surgical skill during phase 2 of the performance curve, to evaluate the effect of computer game playing on phase 1 of the performance curve and to compare virtual reality training to the training modality with highest fidelity, live animal training.

2 AIMS

1

Is virtual reality simulator training equal to physical reality simulator training in increasing robot assisted laparoscopic suturing skills?

2

Can virtual reality training per se increase manual laparoscopic suturing skills?

3

Can previous computer game experience be used to predict performance on a virtual reality laparoscopic simulator?

4

Do surgeons in training find virtual reality simulator training comparable to animal training?

3 MATERIAL AND METHODS

3.1 Simulator

The SimSurgery Education Platform (SEP) version 1.03 virtual reality simulator from SimSurgery AS (Oslo, Norway), was used for study 2 and 3. Version 1.03 and 2.0 was used for study 4. The simulator exercises included in these studies were available in both versions of the simulator. The two simulator versions differ only slightly in hardware design.

The simulator software runs on standard PCs with graphics card for gaming and Windows OS. The SEP system includes a generic laparoscopic user-computer interface, called SimPack. Position and orientation of various instruments, including endoscope, needle drivers, and graspers are tracked with an electromagnetic motion tracking system. These positions and orientations, together with grasper opening and other signals are fed into the simulation software through the USB port on the PC. These input signals control the virtual instruments in the simulator exercises. The tracked instruments are inserted through ports that can be placed in different positions on a generic surface, mimicking the abdominal surface of the patient (Fig. 3).

For study 1 SimSurgery developed a module for robotic suturing using the master console and screen from the Zeus robotic surgical system (Computer Motion) (Fig. 4).

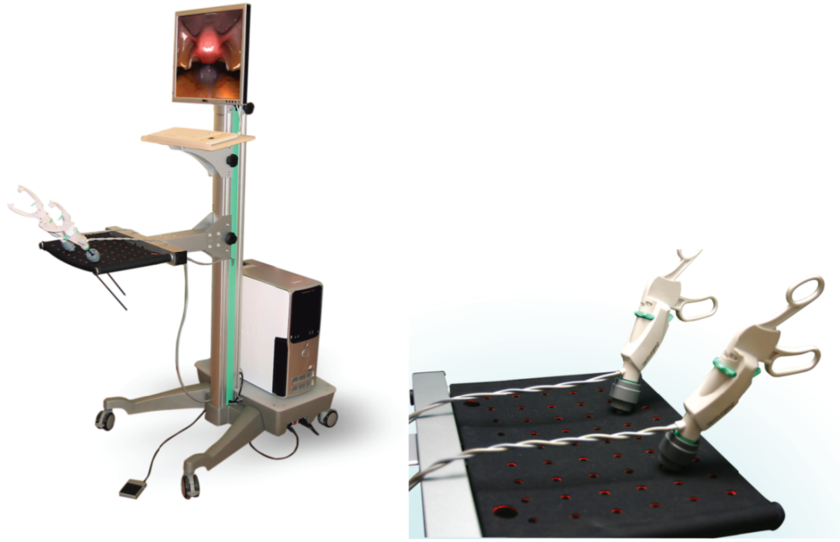

Figure 3: The virtual reality simulator SEP (Surgical Education Platform) from SimSurgery
Simulator hardware with close-up of human computer interface.

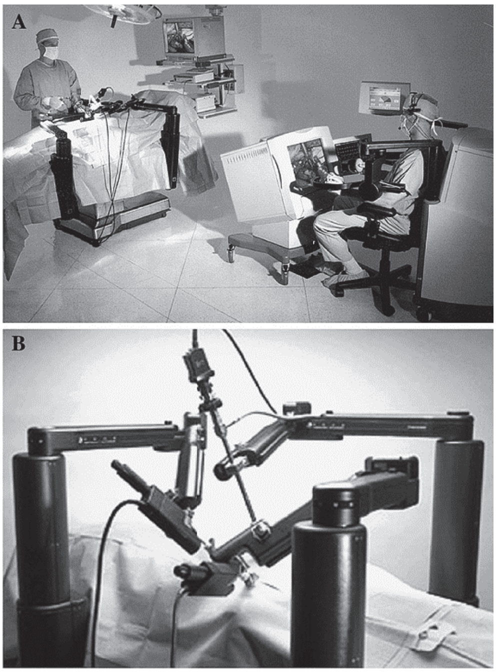

Figure 4: The Zeus robotic surgical system
The system was developed and produced by Computer Motion and was discontinued in 2003 when Computer Motion merged with Intuitive Surgical. The system consisted of a master console where the surgeon controlled the two robotic arms visualised on a screen on the master console. During virtual reality training, the arms where disconnected and the master console was used to control two virtual reality instruments visualised in a similar way (see Figure 12). Picture downloaded from http://www.springerimages.com/Images/MedicineAndPublicHealth/1-10.1007_s11701-006-0007-5-0

3.2 Exercises:

Only exercises where both hands had to be used to interact with a virtual environment were included in these studies. The virtual environment was simulated organs in some exercises while other exercises only focused on manipulation of an object in a non-anatomical environment.

The exercises included was “Traverse tube”, “Place arrow”, “Adjust needle by pushing the needle”, “Free adjust needle”, “Two-handed stitch”, “Abstract continuous suture” and “Gall bladder dissection” for the laparoscopic studies and “Robot assisted suturing” for the robotic study. See Figure 5 – 12.

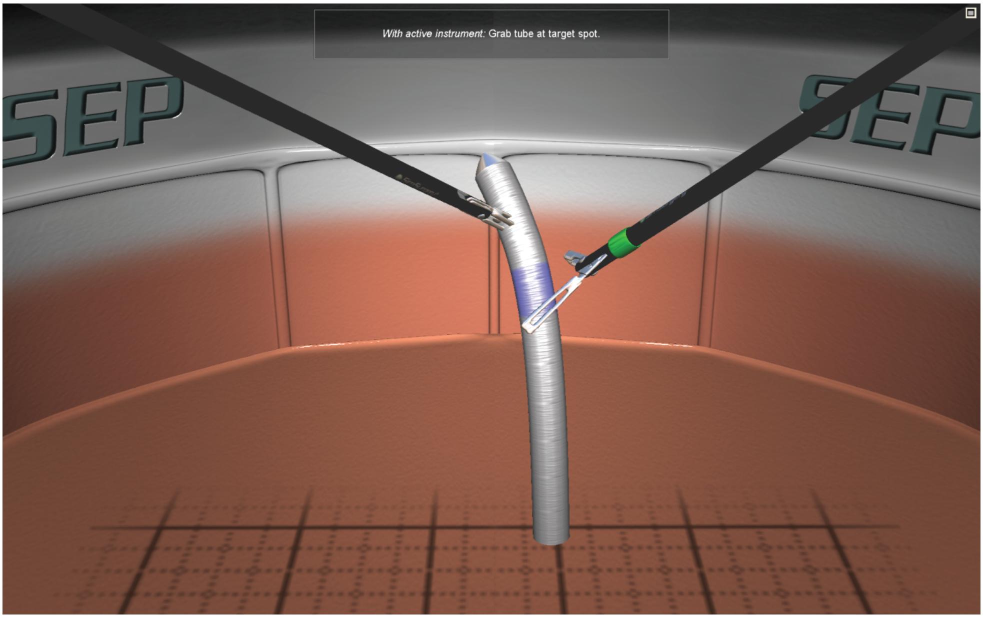

Figure 5: Traverse tube

The active instrument has a green marker around the distal part of the shaft, and this instrument is used to grasp the tube at the target area. Once the tube is grasped at the target area with one instrument, the other instrument is marked with the green marker and a new target area appears distally on the tube. The other instrument then grasps this new target area. This sequence of steps is repeated and the tube is traversed in both directions for a set number of times.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments)
Errors: Dropped tube, Grasped outside target area

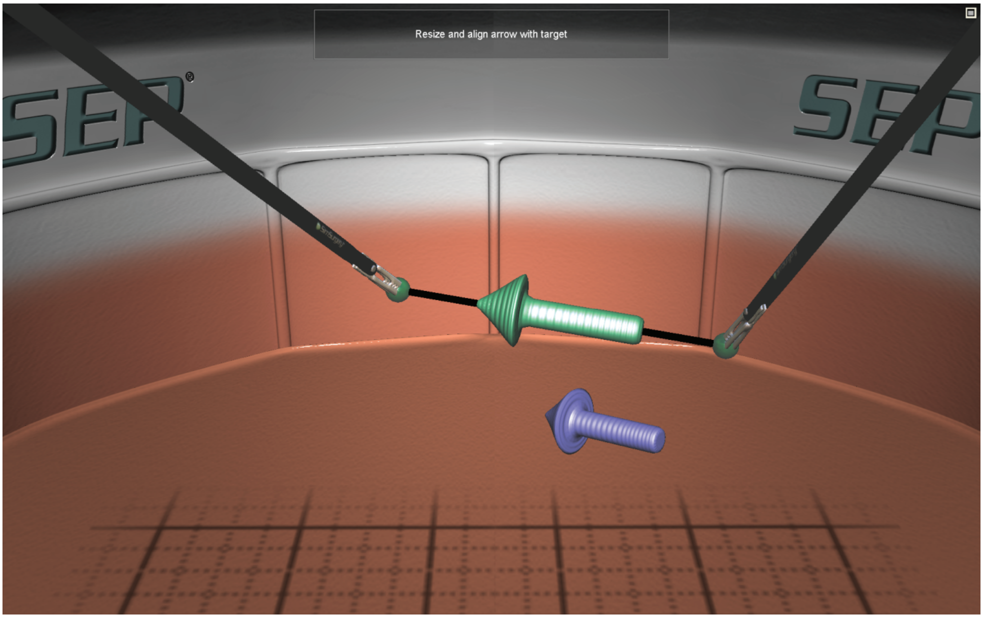

Figure 6: Place arrow

The arrow is grasped in both ends at the spheres using the graspers. Using both graspers the arrow is then placed "inside" the preplaced arrow. Both direction and length of the arrow must be correct. When correct placement is achieved, both arrows turn green. The correct position must be held for a specified time interval before the manipulated arrow returns to its original position and the target arrow disappears. A new target arrow reappears, and the sequence of steps is repeated.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments)
Errors: Dropped arrow, Slipped arrow (if the arrow is compressed or stretched too much), Closed entry (if one or both of the instruments enter the sphere closed)

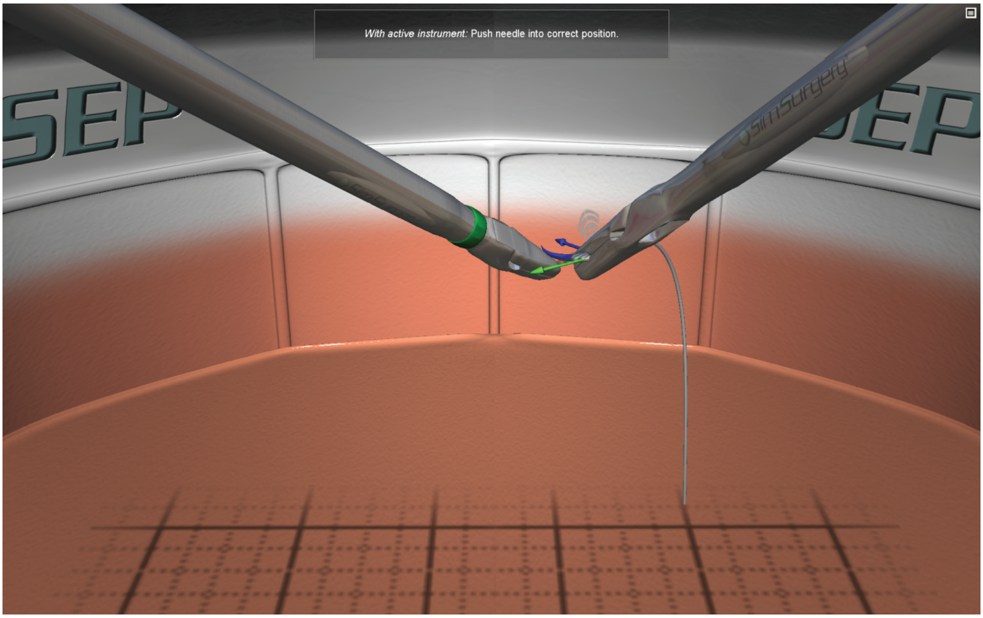

Figure 7: Push needle to adjust needle:

The active instrument has a green marker around the distal part of its shaft, and this instrument is used to grasp the needle at the target area. Once the needle is grasped correctly, the other instrument is used to push the needle into correct position. The position of the needle must be correct around two axes: the tangential axis of the needle curvature where the needle is grasped by the instrument and perpendicular to this axis. When correct position is achieved the needle is held in this position for a specified amount of time.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments)
Errors: Dropped needle, Adjustment failed (number of time the needle is adjusted from a correct position in one plane to an incorrect position in the same plane), Closed entry (when the active instrument enters the needle closed when it is supposed to grip it), Wrong segment (when the needle is grasped outside the target area)

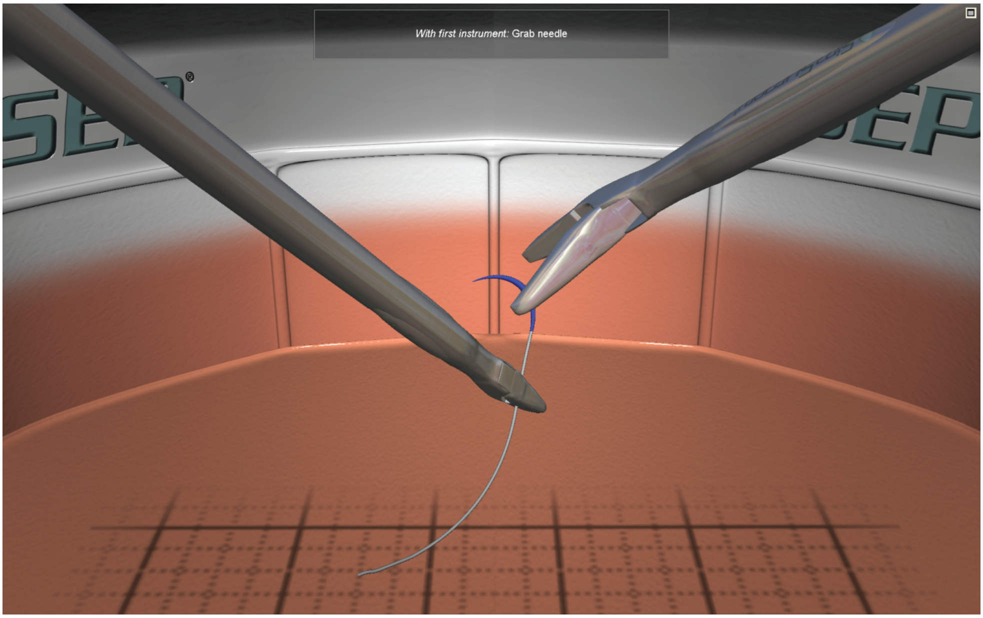

Figure 8: Free adjust needle

The needle can be grasped using one of the instruments and the orientation of the needle can be manipulated by pulling the tread, pushing the needle using the other instrument or by passing the needle from one instrument to the other. The position of the needle must be correct around two axes: the tangential axis of the needle curvature where the needle is grasped by the instrument and perpendicular to this axis. When correct position is achieved the needle is held in this position for a specified amount of time.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments)
Errors: Thread overstretch (number of ttime the tread is stretched beyond its breakingpoint), Adjustment failed (number of time the needle is adjusted from a correct position in one plane to an incorrect position in the same plane)

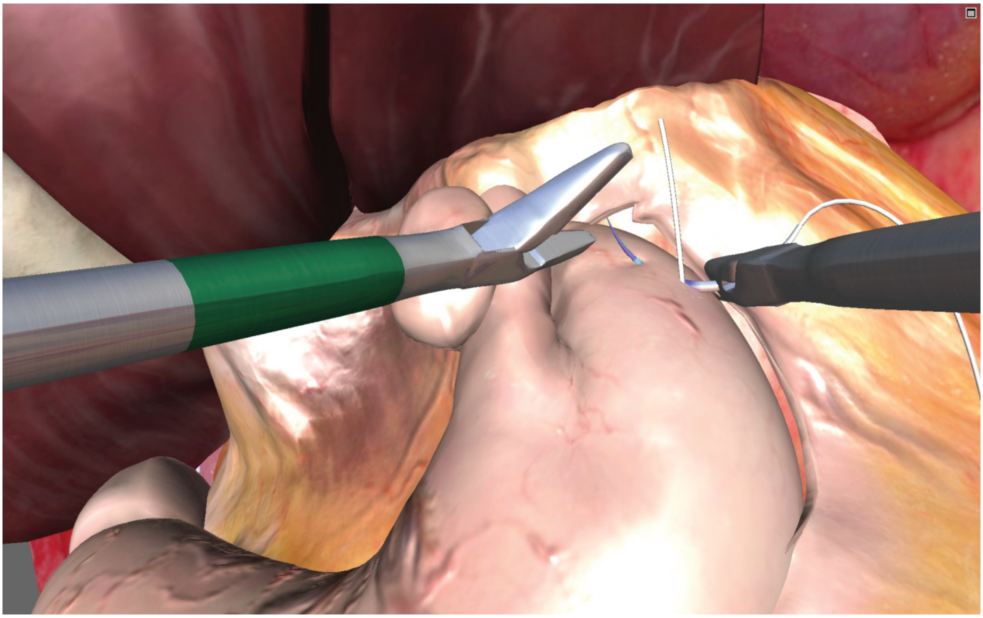

Figure 9: Two handed stitch

The active instrument has a green marker around the distal part of its shaft, and this instrument is used to grasp the needle at the target area. Once the needle is grasped correctly two spheres appear. The blue defines the needle entry point and the gray its exit point. The active instrument is used to pierce both speheres with the needle followed by needle removal by the other instrument grasping the needle at the target area on the tip of the needle. The tissue is deformable, and the needle will cut through it if it stretches the tissue too much.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments), Entry hit deviation, Exit hit deviation (distance between hit point and marked entry and exit point), Max entry stitch deformation, Max exit stitch deformation (maximum tissue deformation during entry and exit of the needle)

Errors: Excessive traction, Hits outside entry, Hits outside exit, Stitch overstretch during entry, Stitch overstretch during exit, Incomplete stitch entry, Incomplete stitch exit, Dropped needle, Closed entry (needle entered with closed instrument), Wrong segment (needle grasped outside target area)

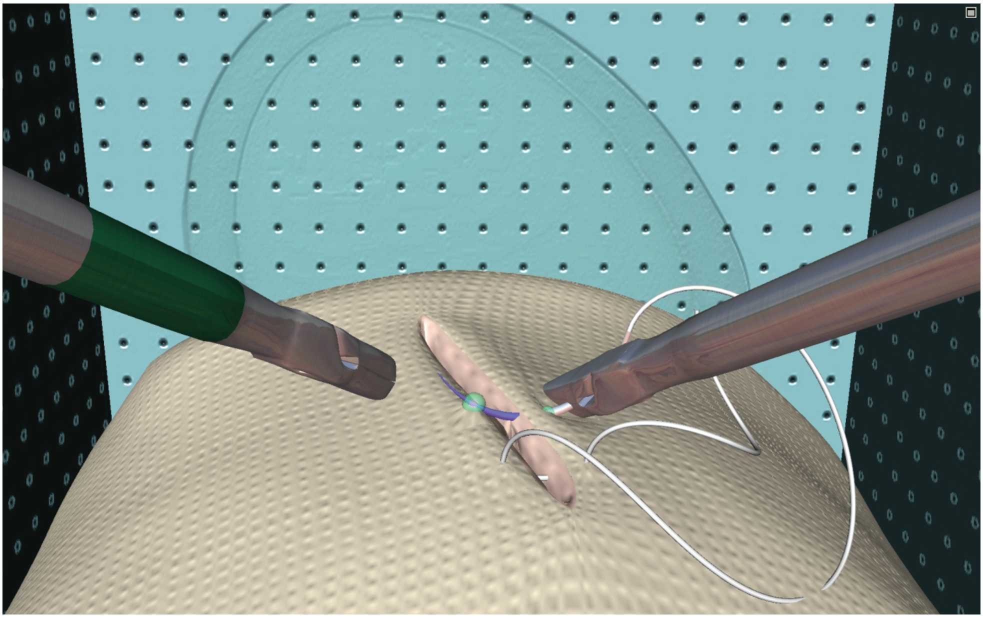

Figure 10: Abstract continuous suturing

The active instrument has a green marker around the distal part of its shaft, and this instrument is used to grasp the needle at the target area. Once the needle is grasped correctly two spheres appear. The blue defines the needle entry point and the gray its exit point. The active instrument is used to pierce both speheres with the needle followed by needle removal by the other instrument grasping the needle at the target area on the tip of the needle. The tissue is deformable, and the needle will cut through it if it stretches the tissue too much.

These steps are repeated three times performing the continous stitches.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments), Entry hit deviation, Exit hit deviation (distance between hit point and marked entry and exit point), Max entry stitch deformation, Max exit stitch deformation (maximum tissue deformation during entry and exit of the needle)

Errors: Excessive traction, Hits outside entry, Hits outside exit, Stitch overstretch during entry, Stitch overstretch during exit, Incomplete stitch entry, Incomplete stitch exit, Dropped needle, Closed entry (needle entered with closed instrument), Wrong segment (needle grasped outside target area)

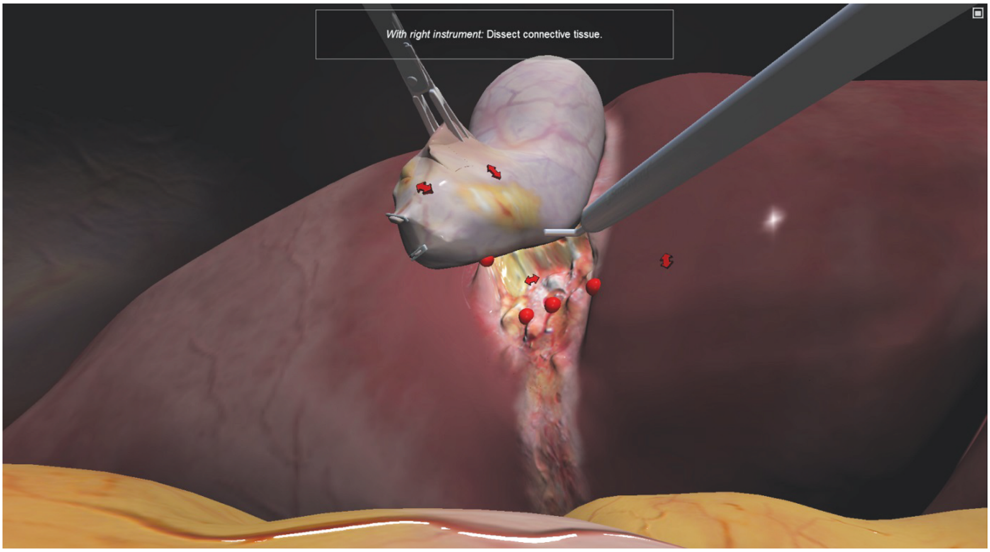

Figure 11: Dissect gallbladder

The grasper is used to grab the gallbladder at the target area. The gallbladder is retracted visualising its attachement to the liver bed, and the gallbladder is dissected from the liver bed using an electrocautery hook until it is completely free. If electrocautery is applied to either the gallbladder or liver bed, red spheres appears.

Metrics: Total time, Tip trajectory (the total length of movement for both instruments)
Errors: Excessive traction (number of times the gallbladder is retracted to far resulting in the gallbladder being released from the grasper), Electrocautery on opposite instrument (number of times when electrocauetry is active and colliding with the grasper), Electrocautery on non-target tissue (number of times the electrocautery is used on non-target tissue), Electrocautery in air (the total time when electrocauetry is active without touching the tissue)

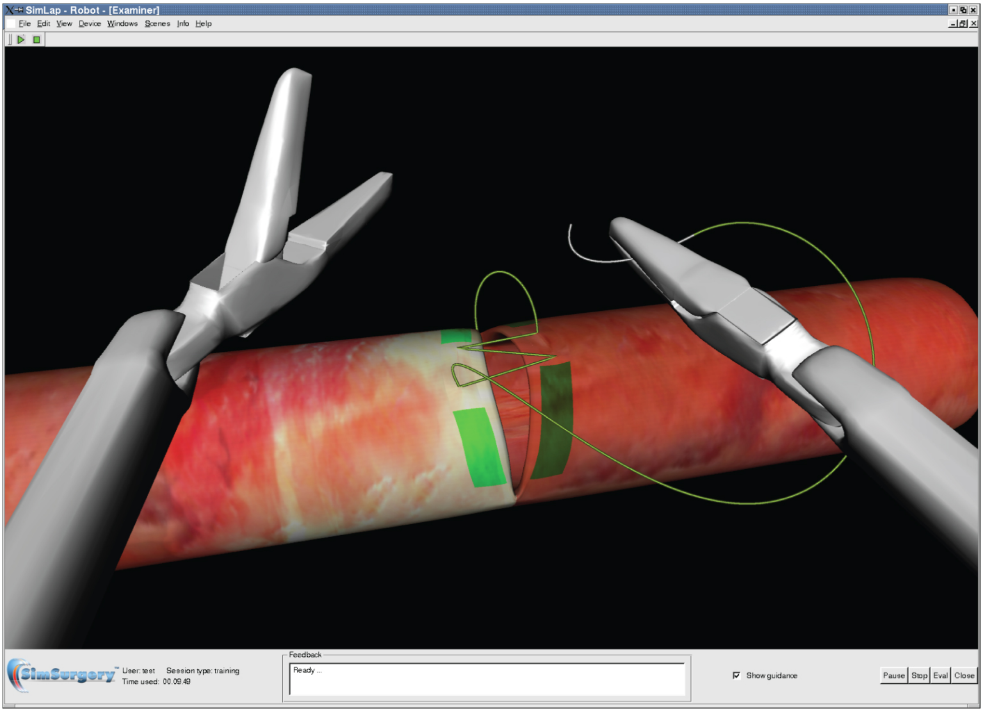

Figure 12: Robot assisted suturing

The right instrument is used to grasp the needle. The needle is positioned in the needle holder and continuous suturing is performed. The stitches must be placed within the marked area on both sides.

Metrics: Number of stitches, Stich placement (visualised on a figure showing optimal stitch placement regarding distance from anastomosis and actual stitch placement)

Errors: None recorded

3.3 Test subjects

The test subjects in the different studies were 26 medical students (Study 1), 26 internship candidates (Study 2), 45 high school students (Study 3) and 54 surgical residents (Study 4).

3.4 Study design

In both training studies (Study 1 and Study 2) a similar design was used; a pre-test in a box trainer was followed by randomization of the participants into two groups. The two groups were randomized to virtual reality training or training using the whole robot in Study 1. In Study 2, one group did not receive further training after the pretest, functioning as a control group. After the training period both groups underwent a test identical to the test prior to training (post-test) (Figure 13). The pre-and post-test in study 1 and 2 was placing stitches on an explanted pigs heart (Study 1) and intestines (Study 2). The results in the post-test were compared to the results in the pre-test for each participant.

Simulator exercises used were "Robot assisted suturing" (Figure 12) for Study 1 and "Traverse tube", "Place arrow", "Adjust needle by pushing the needle", "Free adjust needle", "Two hand stitch" and "Abstract continuous suture" (Figures 5-10) for Study 2.

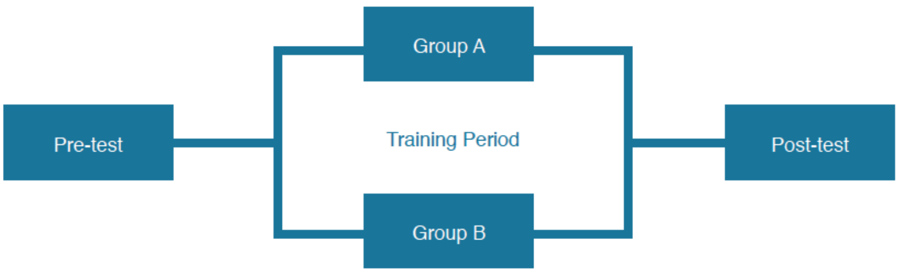

Figure 13: Study design for Study 1 and 2

In study 3 all participants filled out a questionnaire regarding previous and current computer game playing before performing two repetitions of two tasks in the virtual reality simulator. Their performances were evaluated using simulator generated metrics. Mean scores for the two repetitions were used. Simulator exercises included "Traverse tube" and "Dissect gallbladder" (Figures 5 and 11). Data were investigated for association between previous and current computer game experience and performance on the virtual reality simulator.

In Study 4 surgical residents attending an annual compulsory course in thoraco-laparoscopic surgery were asked to compare virtual reality simulator training to live animal training using a five point Likert scale.
Simulator exercises included “Traverse tube” and “Dissect gallbladder” (Figures 5 and 11).
All participants filled out a questionnaire regarding age, previous experience in surgery and previous experience in laparoscopic surgery.

3.5 Metrics
Metrics used in the studies investigating simulator training effect on robot assisted and manual laparoscopic suturing skills were; number of stitches, self-evaluated understanding of the task, self-evaluated quality of performance (Study 1), time to place first stitch, number of stitches, number of times dropping the needle (Study 2). Due to limited economic resources, motion analysis devices were not used to evaluate technical skills.

In study 3 simulator generated metrics were used to evaluate virtual reality simulator performance (total time, tip trajectory, dropped tube and wrong segment burning in air, tissue overstretch, burning on tool and dissected outside target).
Simulator performance was investigated for association to previous and current computer game playing.

When comparing live animal training and virtual reality simulator training, the two training modalities were evaluated by the participants using a five point Likert scale with regards to relevance of training, the ability of the training modality to recreate movements used in laparoscopic surgery, feedback given during training, the relevance of feedback received during training and time used train using the two different training modalities.

3.6 Statistics
In all studies a statistician was consulted to find the most suitable statistical method to analyze the data.

The data were not normally distributed and in study 1 and 2 Wilcoxon signed ranks test was used to compare performance in the pre- and post-test within each of the groups (two related samples). When comparing the performance of both groups Mann-Whitney WILCOXON test was used.

In study 3 the crude association between computer game playing and categorical variables recorded by the simulator was assessed with chi square tests. To compare performance between several groups with different levels of computer game experience measured as a continuous variable, a non-parametric Kruskal-Wallis test ("black ANOVA") was used.
In study 4 the association between participant demographics and simulator validation as well as the association between the simulator performance and simulator validation were assessed using Spearman correlation coefficient.
In all studies $p<0,05$ was considered statistically significant and all tests were two-sided. All studies were regarded as exploratory, therefore we did not perform any correction for multiple testing.

4 RESULTS

4.1 Study 1

The number of stitches placed during the post-test was significantly higher than number of stitches placed during the pre-test for both groups. The increase in number of stitches was also similar when comparing the virtual reality simulator trained group and the dry-lab trained group. Both groups had a similar increase in self-evaluated performance.

4.2 Study 2

For the simulator group, there was a statistically significant decrease in time to complete the first stitch and an increase in total number of stitches when comparing the pre- and post-test. Similar results were found for the control group. None of the groups had a significant reduction in number of times they dropped the needle during suturing (Table 3 and 4).

4.3 Study 3

Forty-three of the 48 students (90%) played computer games during the previous year, and 41 of the 48 students (85%) played computer games three years ago.
Of the 43 students playing computer games during the previous year, 26 (60%) played action games while 22 (54%) played action games three years ago. Fifteen students (31%) played action games in both periods.
Only 5 students (10%) did not play computer games during the previous year. Of these 5 only 2 (4%) did not play computer games three years ago, meaning that 96% of the whole sample had played or were playing computer games at the time this study was conducted. The amount of computer game playing was high: almost half of the individuals in our sample played computer games more than 6 hours per week during the previous year, and almost half played computer games more than 11 hours per week three years ago.

No difference in performance on two different exercises in a virtual reality simulator was found when comparing “action-game players” and “non-action-game players”. The results did not change when we divided the experience with action game playing into three categories: action game playing during the previous year, action game playing three years ago or action game playing three years ago and during the previous year. Nor did we find any association between time used playing computer games of any type (not only action games) and performance on the simulator.

4.4 Study 4

The median score for animal training was 5 on all variables except for feedback on performance which received a median score of 4. The median score for simulator training was 3 for all variables.

The difference between the two training modalities was found to be small with regards to the relevance of training (a difference in score of 1 or less) by 44 % of the participants. Regarding the training modalities` ability to recreate movements and to give feedback, the difference in rating was also found to be small (a difference of 1 point or less) for one third and half of the participants respectively.
One third scored animal training 3 or 4 points better than simulator training with regards relevance of training and the ability of the training modality to recreate movements needed in laparoscopic surgery.

Participants with less experience in laparoscopic surgery gave the virtual reality simulator a higher score compared to participants with more laparoscopic experience.

No association was found between simulator evaluated surgical performance and how high the participant`s scored the simulator as a training modality.

5 DISCUSSION

Study 1 and 2 investigated the effect of virtual reality simulator training during phase 2 of the performance curve, study 3 investigated the effect of previous computer game experience on phase 1 of the learning curve and study 4 compared virtual reality training with the highest fidelity training modality currently available; live animal training.

5.1 Study 1 and 2

Both these studies used a distributed training program. Participants in both studies volunteered to participate, indicating that they were motivated to take part in the training program. While training in study 1 included only suturing, study 2 included different exercises. These exercises were chosen to adhere to the principles of learning basic skills first (using both hands to manipulate an object in a 3 dimensional environment visualized on a 2 dimensional screen) and part task training (two exercises focusing on needle placement, one exercises focusing on using both hands to place a single stitch and on exercise focusing on placing a continuous suture).

We chose to test surgical skills directly using similar test-exercises before and after training since there is no clear correlation between neuropsychological tests in general and surgical skills[14,40,71,213-215] in the same way performance in on motor task can be used to predict performance on another motor task[216].

In study 1 we found that virtual reality simulator training equaled training using the whole robot when comparing two groups of medical students with no prior experience in laparoscopic or robot assisted suturing skills. This was the first published study which focused on virtual reality simulation in robotic surgical training[217]. Later studies have found similar results as in study 1. Two systematic review articles published the last two years have concluded that virtual reality simulator training will play an important role in robotic surgical education[217,218]. They suggest that these simulators should be used in the early part of training and as part of a curriculum that should include traditional training in the operating room. Two similar studies not included in these review articles conclude that simulator training may have effect in the early part of training[219] and that virtual reality simulator training in addition to training using a hybrid simulator may increase robotic surgical performance in novice subjects[220].

The main limitations of study 1 are that the pretest was relatively long (40 minutes) which may have led to a learning effect in itself. The relatively large increase in sutures placed indicates however that an additional training effect was added by the training period. The evaluator was not blinded, but using a quantitative measure reduces the chance of assessment bias. That the study only included one objective parameter is another limitation. If motion analysis had been used in addition, the results may have been different.

The population sample was medical students. This population is often used in simulator studies. The main advantage is that they are at the early, steepest part of the learning curve and increase in skills will therefore be easier to detect than if using experienced surgeons higher on the learning curve. There is no clear difference when comparing surgeons to non-surgeons with regards to motor skills not related to a specific surgical procedure[88,176,221-226] or increase in surgical skills as result of training[227]. We therefore believe the results can be generalized to a population of surgeons because no studies have been able to show that surgeons acquire motor skills faster than medical students.
The study only included 26 participants. If there are subtle differences between the two training modalities, this may not have been detected, resulting in a type 2 error.

In study 2 both groups were tested prior to randomization. The test consisted of placing a continuous suture on explanted pig's intestines. The same test was performed after a training period where half of the participants received 4 training sessions during 6 weeks. The training consisted of performing the exercises on the virtual reality simulator and receiving feedback from the simulator. The training was predefined and included 6 simulator exercises. All exercises had to be performed during each training session.

Both groups showed an increase in skills when comparing the pre- and the post-test with regards to time to place first stitch and number of stitches placed. There was however no difference between the simulator-trained group and the control group with regards to increase in skills. Since the control group increased their performance between the pre- and post-test, this indicates that the pre-test itself had a training effect which also has been observed in other studies[142]. A longer training period may therefore have been necessary in study 2 to detect a further increase in skills or to overcome a plateau phase (see Figure 2).

Most of the published studies include feedback from an instructor and/or operating room training in addition to simulator training. The advantage of our study is that it only included simulator training.

Study 2 indicates that simulator training per se may not be sufficient in order to increase suturing skills. One of the reasons may be that the simulator generated feedback is not sufficient.

Feedback given during training can be internal and external[228]. External feedback is given to the trainee by an external evaluator, either a person or a machine. Internal feedback is given to the trainee by him- or herself.

Feedback may further be divided into outcome feedback or process feedback[108]. Outcome feedback is given when performance is finished, while process feedback is more detailed feedback on correct and incorrect behavior during performance. The simulator generates both types of feedback. During the early part of training too little or too intense feedback may overwhelm the trainee's attentional capacity and reduce training effect[108,229,230]. Maximum training effect is therefore dependent on optimal feedback[231]. As training results in increased skills, the need for external feedback is reduced as the ability to give correct internal feedback increases.

The conclusion in study 2 that simulator generated feedback may not be sufficient to increase laparoscopic skills is supported by a study by Stranbygaard et.al. The found that a group of students who received standardized feedback from an instructor reached expert level on a virtual reality simulator faster than a group of students who did not receive feedback[232]. Individually tailored feedback may have increased the difference between the two groups even more. These results indicate that feedback from an instructor/mentor may be needed for simulator training to be effective in increasing technical skills. Similar results were found by Van Sickle et.al. who concludes that type and quality of feedback have a large effect on increase in technical skills[233]. The role of the mentor may therefore still be viewed as one of the most important factors that influences the surgical trainee's performance resulting in competent surgeons[234-236], which is also the conclusion in recent meta-analysis by Al-Kadi et.al.[237]

Study 2 has limitations; the training sessions were of a specified length. Using a proficiency based training curriculum[93,238-240] may have yielded different results. The interval between the training sessions may also have been too long. This implies that the skills learned in one training session may not have been retained to the next training session.

The effect of simulator training may have been increased by including other exercises, but all included exercises trained both hands, thus focusing on coordinated movements of both hands. Later studies have shown that experienced surgeons uses more simultaneous movements than inexperienced surgeons when performing laparoscopic surgery[241]. The training exercises used in our studies necessitates such behavior.

Training effect depends on optimal stress level during training[242,243]. Including a test at the end of each training session could have increased stress level which also could have increased the training effect in general.

We only used time to evaluate performance. Using additional metrics, including qualitative metrics and motion analysis, may also have yielded different results.
Different metrics have been used to describe surgical technique, but there is no consensus regarding which metrics that best describes surgical technique. The metrics used in different studies are quantitative or qualitative, subjective or objective and they can be recorded manually or by using motion analysis devices[67,73,141,244-247]. Manually recorded qualitative data are collected more reliably and valid by using structured checklists[50,63,73,248].
The metrics that have been applied in other studies include "time to completion", "path length", "economy of motion", "precision", "number of movements", "speed of movement", "quality of performance on a specific task", "tissue damage", "number of correctly performed tasks", "number of errors", "tissue handling" [5,79,114,120,121,132,135,137,143,147,249,250].

The number of participants in this study is equal to similar studies which conclude that simulator training increases technical skills. The number of participants may have been to low to detect subtle differences, thus resulting in a type 2 error.

We believe the study population is representative for the same reasons as given for study 1.

The difference in results between study 1 and study 2 may depend on the virtual reality simulator training being more similar to real surgery in study 1. When using the master console to control the robotic arms in real surgery, no haptic feedback is given. During the

training period the participants in the virtual reality simulator group, controlled the virtual robotic arms using the master console. This lack of haptic feedback in both live and simulated surgery in addition to the master console being identical when performing live and simulated suturing may have resulted in the higher training effect as compared to the training effect in study 2.
When the participants use the virtual reality simulator to train manual laparoscopic skills, the instruments used differed from the instruments used when doing real laparoscopic surgery. In addition, tactile feedback in real laparoscopic surgery is not simulated by the virtual reality simulator. Tactile feedback has been shown to be difficult to mimic by virtual reality simulators and it has been question whether simulation tactile feedback is necessary for a simulator training to increase surgical skills[251,252].

Furthermore, the training effect that may have been based on the similarities between real and simulated surgery in study 1, may have been further reinforced by robot assisted suturing being more demanding than laparoscopic suturing. When doing a more demanding task, a potential plateau phase would take longer to reach. This implies that it is possible to detect an increase in skills over a longer period of time.

5.2 Study 3

Study 3 aimed at investigating the possible effect of previous computer game experience on laparoscopic skills evaluated by a virtual reality simulator. In this study 45 high school students performed two repetitions of two tasks on the virtual reality simulator. All students completed a questionnaire regarding previous and present computer game playing activity. They were also asked which type of games they played. No difference was found when comparing action game players with non-action game players with regards to performance on the virtual reality simulator. Nor were there an association between the amount of computer game playing in general and performance on the virtual reality simulator.

This was the first study to define where on the learning curve the participants were tested[205]. Post hoc analyses of previously published studies show similar results when the studies are categorized based on where on the learning curve the participants were tested; Computer game playing does not have a clear effect on baseline laparoscopic skills[81,189,191,192,194,196,197,201,208]. Computer game playing may however steepen the learning curve of laparoscopic skills either alone or in conjunction with other type of training[146,153,190,195,196,198-200,202,203,207], but no studies have tested increase in skills tested in the operating room[253].

The studies that tend to find correlation between computer game experience and baseline skills compare subjects with extensive computer game experience with subjects without computer game experience[191,194,204,209].
The amount of computer game playing among the average population has increased tremendously the past 10 years[254]. Future surgeons will therefore most likely be recruited from a population similar to the population sample in our study with regards to computer game playing. The results of this study indicate the individuality of baseline performance will not be affected by previous and current computer game playing experience when testing future surgeons using a virtual reality simulator.

The main limitations in this study are that the simulator may be to crude to differentiate differences in this population sample. Recall bias is another limitation. In addition, most of the participants had been or were playing computer games. This implies that if computer game playing results in increased simulator skills after only a short period of game playing, this would not have been possible to detect in our population sample. This hypothesis is strengthened by the results of Kennedy et.al. who tested gamers and non-gamers on a virtual reality simulator task. They found that gamers had better baseline performance for only one of the three parameters recorded by the simulator (path length)[188]. Similar results was found by Rosenthal et.al who compared children (32 children, age 8,5-12 years) with high versus low video game experience. The results showed a trend towards better performance by children with high video game experience when compared to children with low video game experience when tested on the Xitact virtual reality simulator[204]. These differences were fond for only some parameters, and most parameters did not reach statistical significance.

5.3 Study 4

While study 1, 2 and 3 investigated the effect of virtual reality simulation on two of the four phases of the learning curve, study 4 sought to compare virtual reality training to training using live anesthetized animals.
This is the first study comparing virtual reality simulator training to live animal training. The participants were resident surgeons participating at the compulsory national course in thoraco-laparoscopic surgery in Norway. Live animals used in surgical training are viewed as the

highest fidelity training modality, or simulator. This was confirmed by the study where the participants gave live animal training the highest possible rating for all aspects except feedback. The study also showed an association between experience with laparoscopic surgery and rating of the virtual reality simulator: residents with less laparoscopic experience rated the simulator higher than residents with more laparoscopic experience.

How trainees perceive training is important because it affects motivation. Trainees must be motivated to want to take part in a training program and for training to be effective[102-107]. There are two types of motivation: intrinsic motivation where the trainee is motivated because of personal interest and enjoyment, and extrinsic motivation where motivation is linked to a separable outcome (to obtain a reward or avoid penalty)[255].
Both intrinsic and extrinsic motivation is improved if trainees believe that a specific training program will be useful for his/her daily work[108]. It is therefore important to investigate to what degree surgical trainees find simulator training relevant for their education.

Our results indicate that virtual reality training may be best tolerated in the early part of training. This is in conjunction with other studies who conclude that novices are the target group for virtual reality simulator training[12,143,256-258]. Simulator curriculums and facilities should be designed to meet the demands of this subgroup of surgeons.
It was not possible to calculate a specific “cut off” point with regards to the amount of laparoscopic experience and positive evaluation of virtual reality simulator training.

More time was allocated to live animal training. This may have favored this training modality. This would lead to an underestimation of the perceived usefulness of virtual reality training, hence our results may less in favor for live animal training if allocated time was more equally distributed. Simulators are constantly being improved. Newer simulators may mimic real life to a higher degree, and therefore be even better tolerated by trainees.

The most optimal design for a study comparing live animal training and virtual reality simulator training would make it possible to calculate a transfer efficiency ratio.
Transfer efficiency ratio is a measure of training effectiveness of simulator training compared to the training effect of real surgery on live animals or humans[49]. The transfer efficiency ratio of flight simulators is around 0,5, which means that 1 hour of simulator training equals 30 minutes of real flight training. Reported transfer efficiency ratio for virtual reality simulator in

surgical education has been 0,25 by Satava[49], 0,4 by Cosman et.al.[140], between 0,07 and 0,42 by Gallagher et.al.[259] and 2,28 by Aggarwal et.al.[143]. The transfer efficiency ratio calculated by Aggarwal et.al. is unusually high for any type of simulation. They compared virtual reality simulator training to box training using explanted animal organs and their endpoint was when performance were similar between both groups, not when expert criteria were reached. This may explain the high transfer efficiency ratio.
Planning and performing a transfer efficiency ratio study using live animals would require resources that were beyond the limits of this thesis.

5.4 Summary

On the basis of previously published studies and established learning theories this thesis investigated the effect of virtual reality simulators in laparoscopic surgical education at different places on the performance curve.

The result of study 3 indicates that computer game playing does not increase baseline skills on a virtual reality laparoscopic simulator. Other studies have however shown that computer game playing may increase skills, if game playing is done in conjunction with surgical skills training.

The results of study 1, 2 and 4, indicate that simulators may be used to increase basic surgical skills of novice surgeons, both in manual and robot assisted laparoscopic surgery. These results are backed up by other studies. Integrating simulators may reduce the need of using anesthetized live animals to train basic laparoscopic surgical skills. The training effect of virtual reality simulators seems to be dependent on simulators being part of a curriculum. This curriculum should include theoretical learning, mentoring and feedback and taking part in live surgery[118,231]. Simulators thus hold the potential to add to the Halstedian principle, not replace it; with the implementation of simulators in laparoscopic surgical education, the principle of "see one, do one, teach one" may evolve into the revised principle of "see one, *learn one*, do one, teach one".

6 CONCLUSIONS

1

Virtual reality simulator training equals physical reality simulator training in increasing robot assisted laparoscopic suturing skills.

2

Virtual reality training per se may not increase manual laparoscopic suturing skills.

3

Previous computer game experience does not predict performance on a virtual reality laparoscopic simulator.

4

Surgeons in the early part of surgical training find virtual reality simulator training comparable to animal training.

7 FUTURE PERSPECTIVES

Most simulator studies have focused on the first and second phase of the learning curve; baseline testing and training effect. Some studies have also focused on the third phase: improving performance by adding warm-up sessions before doing actual surgery, both in manual and robotic laparoscopic surgery[260-264]. With increasing computer power and reduced computational cost, it may also be possible to employ patient specific simulation[109,265] in these warm up sessions; i.e. parts of the procedure may be performed in virtual reality before doing the real procedure. Future studies could investigate the effect of patient specific warm-up sessions on operating room performance.

Studies may also focus on using simulators to reduce the decline in skills. Reduced surgical performance may be a result of age induced decline in skills. It may also be caused by periods where the surgeon performs to few procedures to maintain the level of surgical skills. Future simulators could investigate the role of virtual reality simulators in reacquisition of surgical skills[266].

Using other methods to measure skill level may also be used in future studies. One method is to use functional MRI (fMRI) or EEG to map brain activity during surgery[264,267,268]. Future studies may compare fMRI in novices and experts and use fMRI to map changes in brain activity as the trainee traverses phase 2 of the learning curve.

It has been shown that mental training may improve motor skills in general and surgical skills in particular. This form of training has been labeled “imagery practice” or “mental practice”. During this form of training the trainee visualizes the skill to be mastered without actually performing it[92]. When used in combination with motor skill training, the training effect has been found to be greater than if the skill is trained by motor skill training alone[269-271]. The effect of imagery practice is best when a trainee learns skills that requires a high level of cognitive input [272]. This situation is typically encountered when a trainee is in the early stage of learning a task, i.e. in the cognitive stage of learning. Future studies could investigate the effect of mental training on specific surgical techniques but also on surgical strategy, with or without mapping using fMRI.

Individual performance curves all consists of these four phases, but the individual performance curves vary in shape[78,273,274] (Figure 14).

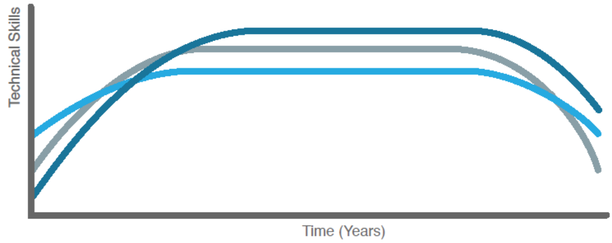

Figure 14: The specific shape of performance curves varies between individuals

Standardized surgical training curriculums are being implemented in surgical education. Future studies could also investigate how to best tailor the curriculum to individual needs, and not only use a "one-size-fits-all" curriculum[275].

This could be done by mapping the individual training needs based on which skills are satisfactory and which are not. Since stress can affect performance in both directions[242,243] optimal stress level for each individual could also be found to optimize training effect; optimal stress level increases performance whereas a too high level of stress or negative stress responses compromises performance. Too low level of stress may also reduce the training effect. Individualized training based on needs and optimal training effect could increase skill level more efficiently than standardized curriculums thereby reducing the length and cost of training.

These tailored curriculums are in contrast to exercises used to test surgical skills. Such surgical test exercises should be standardized to increase generalizability of test results[276]. Future studies should investigate which standardized tests that best predicts live surgical performance, both current and future.

When using simulators to test surgical skills and surgical performance, future studies could include a secondary task. This design has shown to better differentiate between subjects with different level of skills by testing spare attentional capacity[277], and is done by including a visuospatial task that is assessed simultaneously to a surgical task. This design helps to identify spare attentional resources which will increase as he trainee reaches the autonomous stage.

Other fields of medical education use simulators in team training[278]. The effect of laparoscopic simulators as part of a curriculum aimed at surgical team training should be sought in future studies[279].

Most studies have investigated the use of simulators in an experimental setting. Future studies should also investigate how to best implement a surgical training curriculum, including simulator training, in a clinical environment in both academic and non-academic institutions[212,280,281].

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